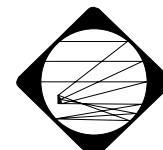


ALI Optical Subsystem Technology

Presented by:

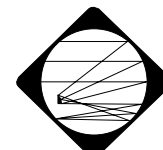
Joe Robichaud
SSG Precision Optronics, Inc.
65 Jonspin Rd
Wilmington, MA 01887
(978) 694-9991
jlr@ssginc.com



SSG
Precision Optronics, Inc.

Technology Description

- **Optical Design**
 - Wide field of view
 - Flat image plane
 - Low distortion
 - Excellent image quality
- **SiC Materials Technology**
 - Hot Pressed SiC Optics
 - Reaction Bonded SiC Optics



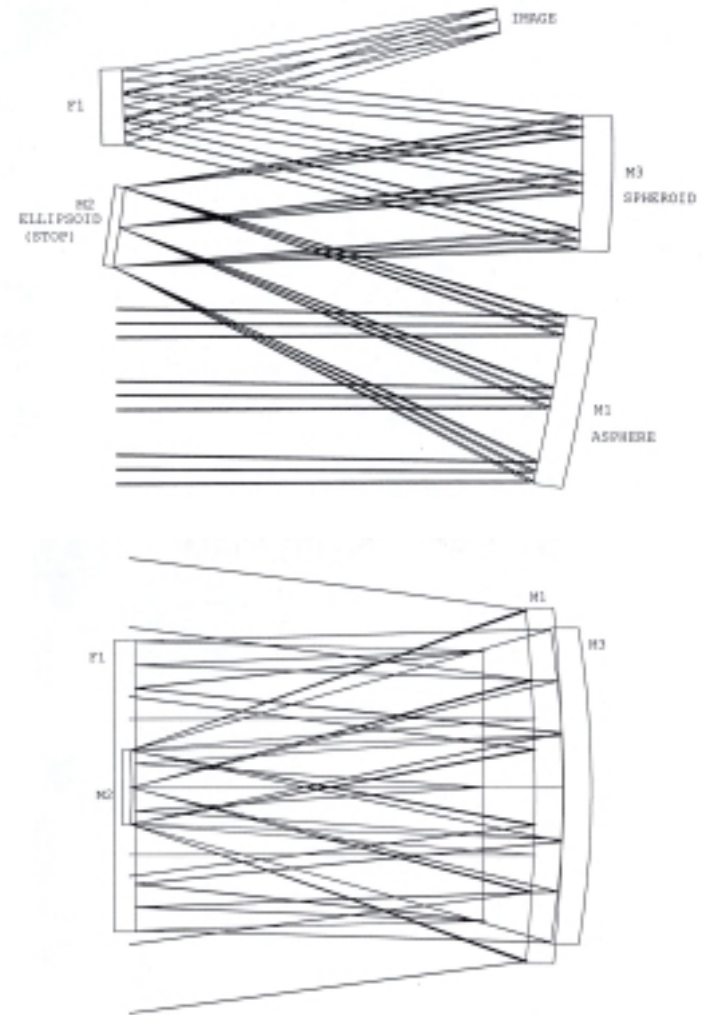
Optical Design Overview

- **Optical Design Form**

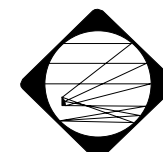
- All reflective Cooke triplet
- On – axis aperture
- Off – axis field of view
- Wide field of view: 1.26 deg x 15 deg set to accommodate FPA
- Non-relayed (no intermediate image)
- Aperture stop on secondary mirror
- Constrained to be near telecentric (< 2.5 deg non-parallel chief rays) in order to maintain standard spectral filter requirements
- Flat image plane
- Low distortion (mappable to $< 10 \mu\text{m}$)
- Excellent image quality (MTF > 0.6 @ 37.5 lp/mm)

- **Optical Components**

- Primary Mirror: Concave general asphere
- Secondary Mirror: Convex ellipsoid
- Tertiary Mirror: Concave sphere

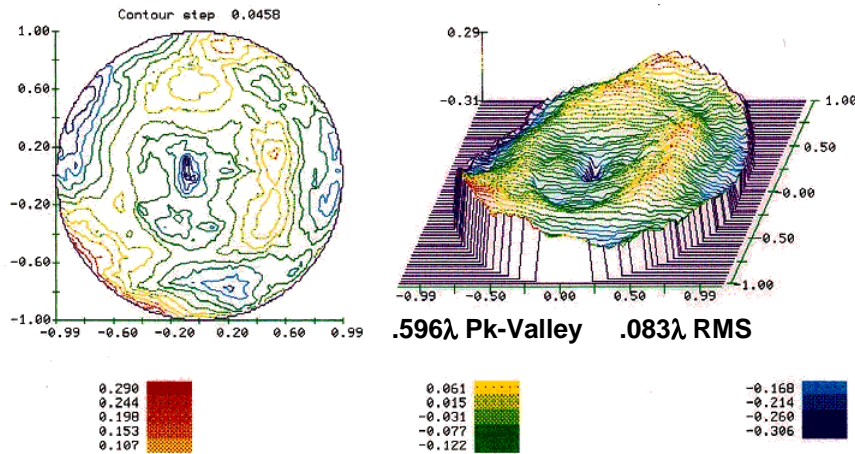


ALI Raytrace

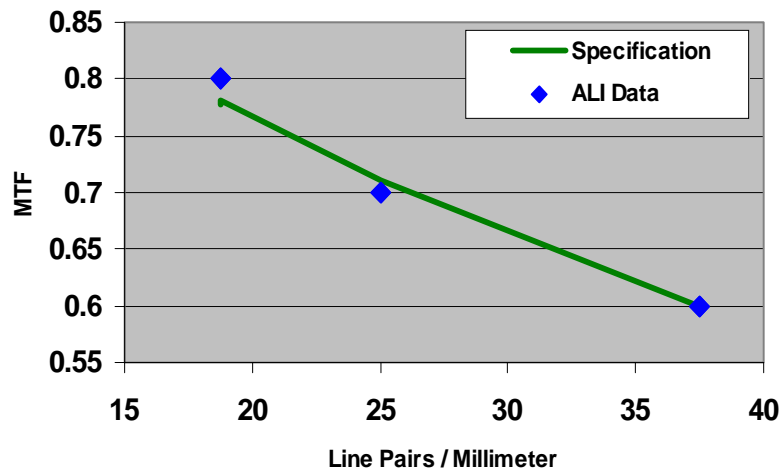


SSG
Precision Optonics, Inc.

Optical Performance Summary (Image Quality)



On Axis, system level WFE



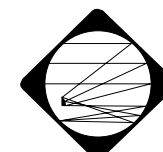
MTF spec and performance

• System Level Wavefront Error

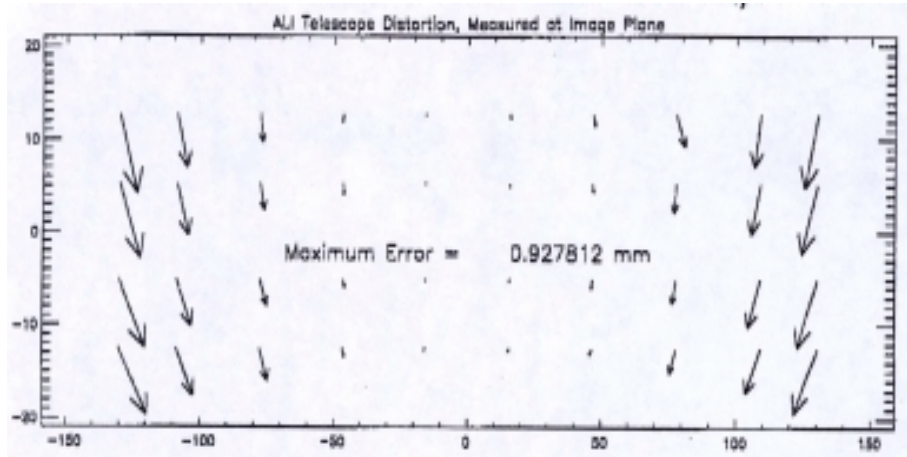
- WFE derived from MTF specification using Code V
- Required system WFE (@ temp) < 0.15 λ RMS (@ 0.63 μm)
- 12 Field points tested, System WFE (@ temp) 0.089 - 0.148 λ RMS (@ 0.63 μm)

• System Level MTF

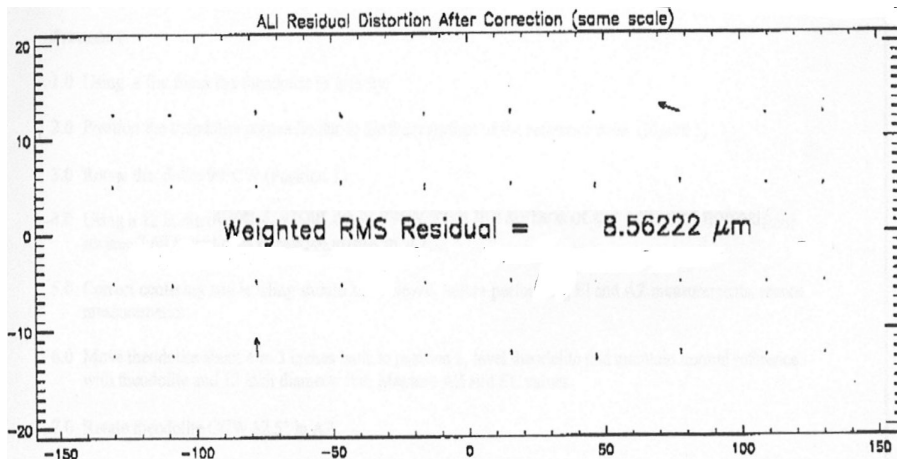
- MTF performance projected from wavefront maps input specification using Code V
- System meets or exceeds spec at 18.75 and 37.5 lp/mm



Optical Performance Summary (Distortion)



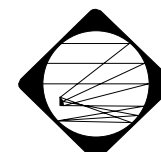
Distortion Map Prior to Correction



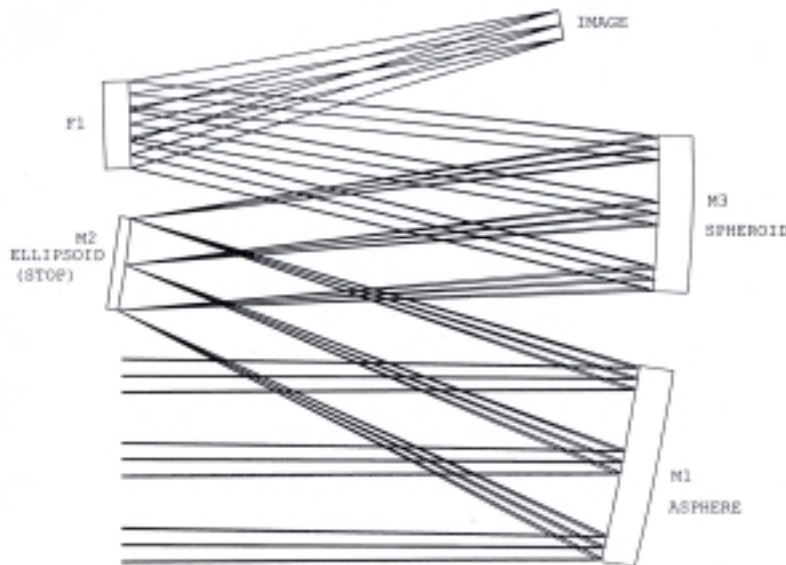
Distortion Map After Correction

- **Optical Distortion**

- Distortion measured by mapping the angular locations of 40 points on a scribed target through the ALI optical system
- Uncorrected data shows maximum distortion vector length of 928 μm
- Cubic polynomial data correction (Dr. David Hearn, MIT/LL) brings residual distortion values down below 9 μm

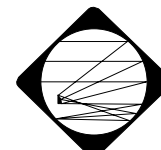


Optical Performance Summary (Stray Light 1 of 2)

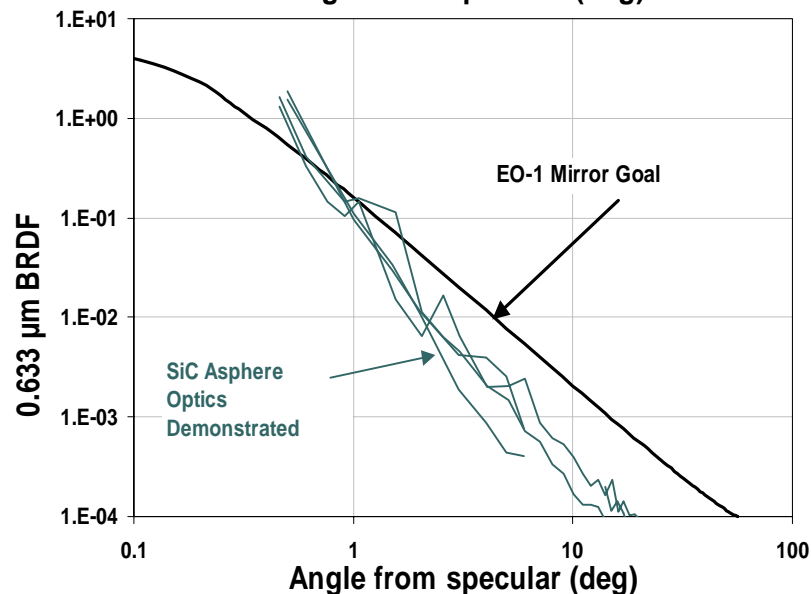
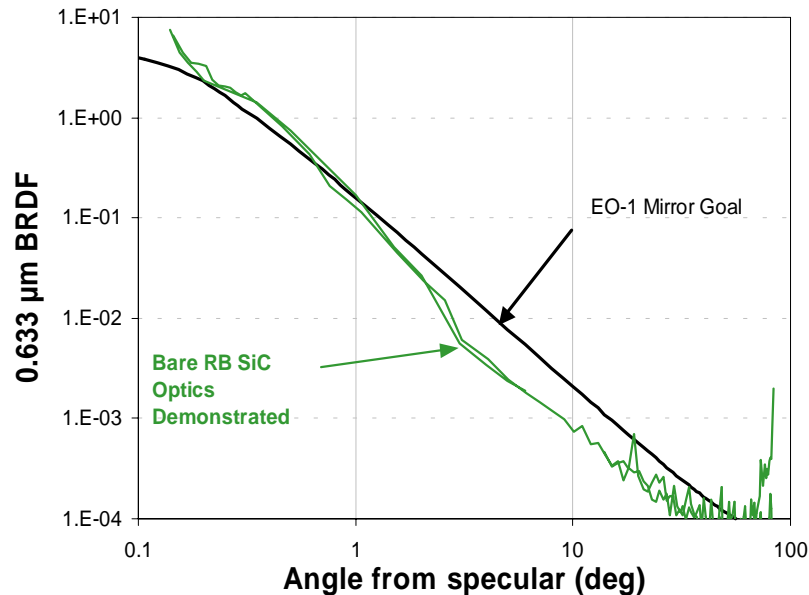


ALI Raytrace

- **System Level Stray Light Performance**
 - Optical design optimized to provide excellent image quality, low distortion, and near telecentric chief rays over a wide FOV
 - Non-reimaged design form is not well suited to stray light suppression
 - As a result, system level stray light performance is dominated by mirror scatter
 - ALI flight optics do not meet system level stray light specifications

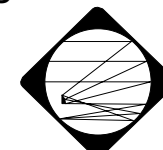


Optical Performance Summary (Stray Light 2 of 2)



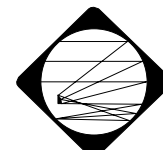
- **Component BRDF Performance**

- Component level BRDF, consistent with all ALI stray light requirements has been demonstrated through a NASA funded technology program
- Silicon clad SiC aspheric optics and uncoated SiC flat optical surfaces demonstrated to have BRDF which will meet all ALI requirements
 - Multiple optics demonstrated, including full scale, ALI primary mirror

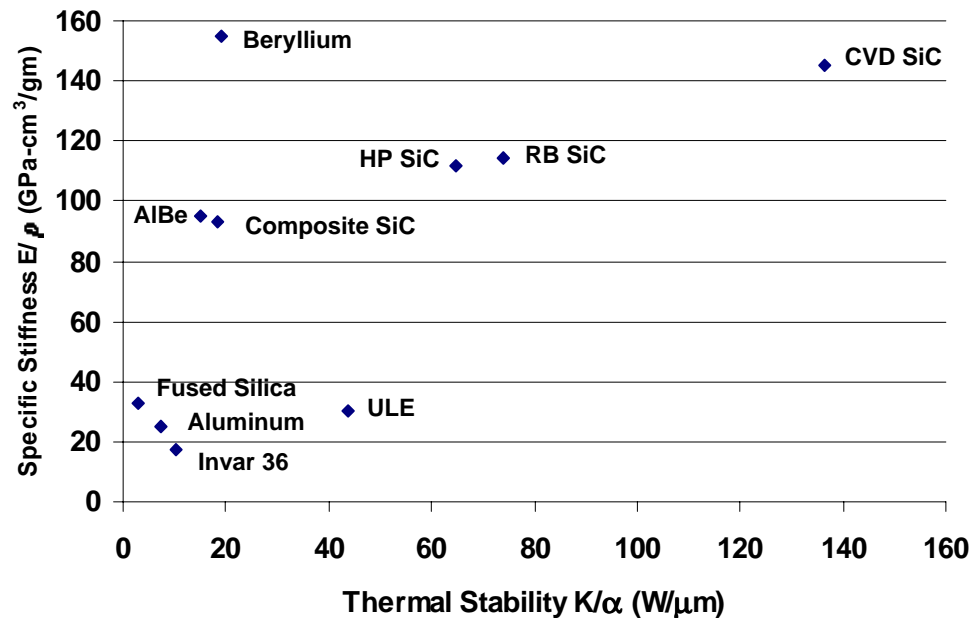


Optical Performance Summary

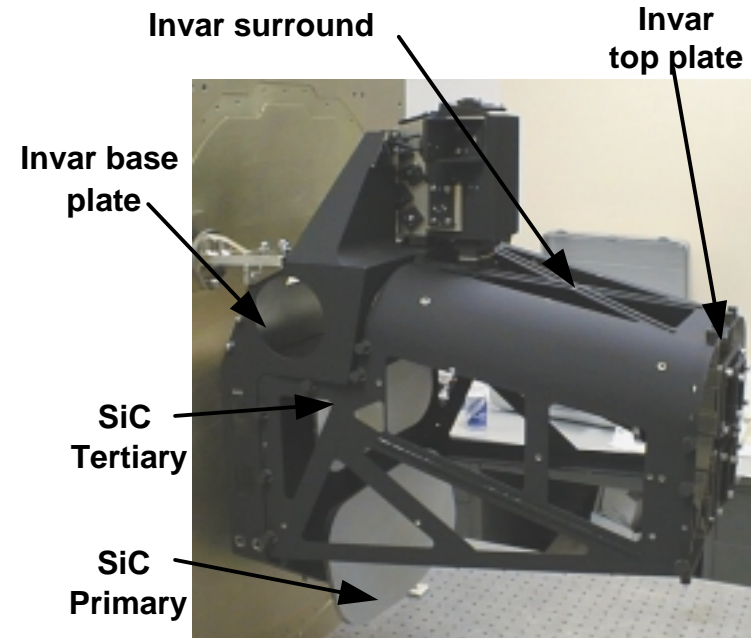
- ALI Optical design form optimized to meet a number of stressing requirements
 - Wide FOV, low distortion, flat field, near-telecentricity, excellent image quality
- ALI SiC optical system meets or exceeds most of the telescope requirements
 - Component level surface figure
 - Distortion map over FOV
 - Reflectivity
 - Focal length
 - Field of view
 - Aperture uniformity
 - Angular resolution
 - Mechanical stability
 - Point spread function
 - Thermal stability
 - System throughput
 - Size
 - Image quality over FOV
 - Weight
- The one exception noted is the system stray light performance of the system and component level BRDF of SiC optics
 - **SSGPO has demonstrated that this is not a limitation associated SiC materials by producing a number of SiC optics (flats and aspheres) which meet all ALI stray light requirements**



Silicon Carbide Material Overview

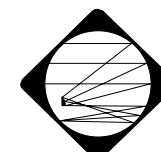


Material Property Comparison

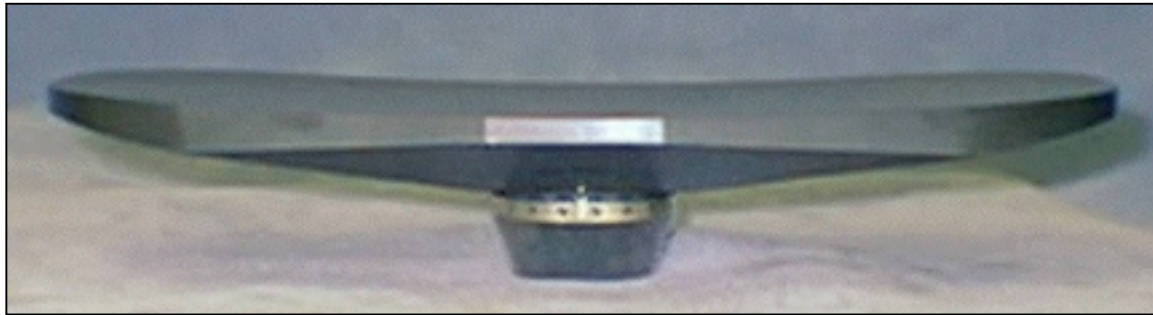


ALI Optical Subsystem

- **Combination of SiC and Invar materials used for ALI Optical Subsystem**
 - Specific Stiffness of SiC (HP, RB, CVD) 70% - 90% of Beryllium
 - Thermal Stability of SiC 3x - 1.5x better than ULE glass
 - Hot Pressed SiC suitable for simple “slab”-type geometries
 - Invar structure selected for its good CTE match to SiC and its good durability

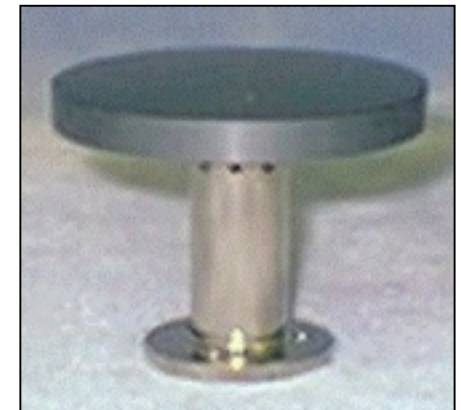


Hot Pressed Silicon Carbide Optics

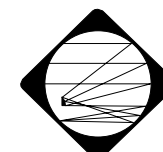


ALI Primary Mirror

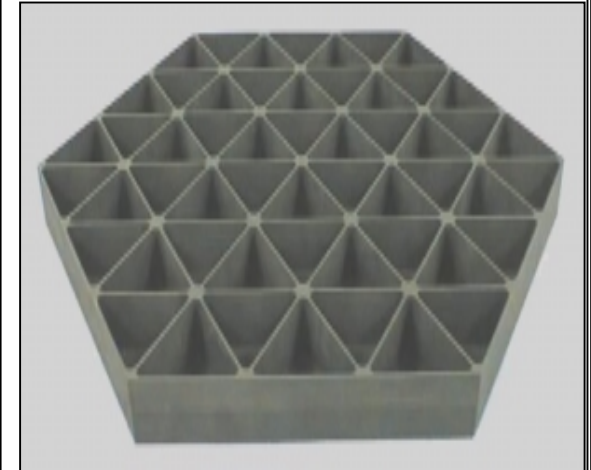
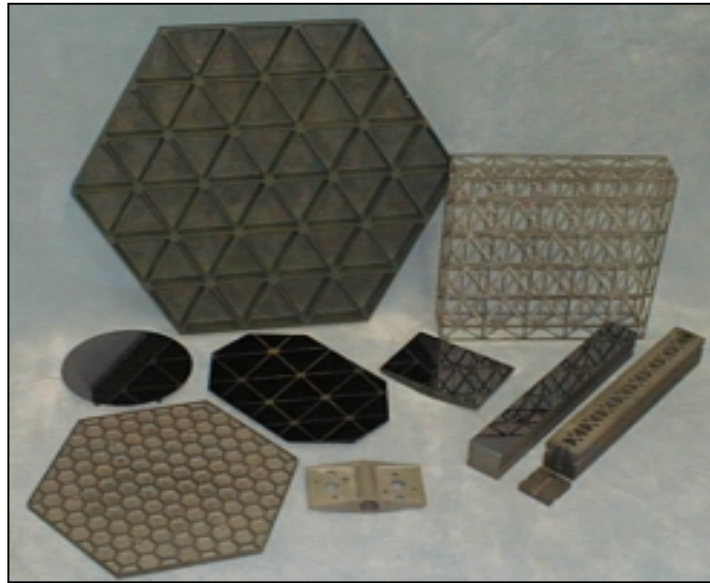
- **Hot Pressed SiC materials used for ALI flight optics**
 - HP SiC has flight heritage
 - SSGPO developed MICAS SiC flight system for NASA DS-1 mission from HP materials
 - HP SiC has excellent material properties
 - Optical grade HP can be figured and finished to produce good quality flat and spherical optics
 - Aspheric optical surfacing requires a silicon cladding
 - HP SiC materials produced in simple slab shapes
 - All lightweighting must be done by aggressive diamond machining
 - Costly and time consuming machining requirements



ALI Secondary Mirror

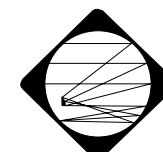


Reaction Bonded Silicon Carbide Optics

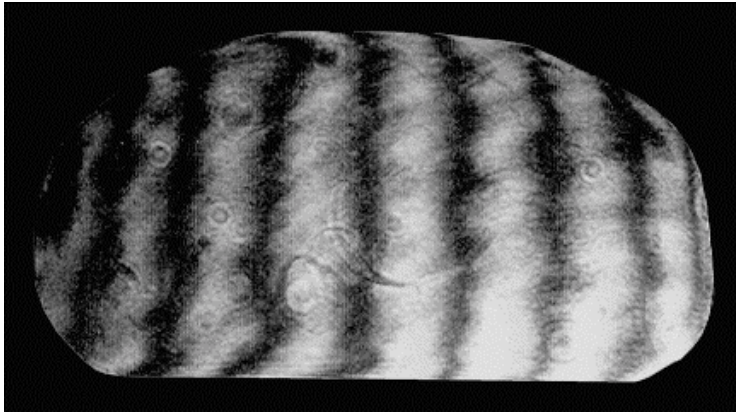


RB SiC Optical and Structural Components

- **Reaction Bonded SiC suitable for more aggressively lightweighted optical and structural requirements**
 - RB SiC maintains excellent material properties while allowing complex structures to be produced with little to no post-machining
 - RB SiC can be figured and finished to produce good quality flat and spherical optics
 - Aspheric optical surfacing requires a silicon cladding

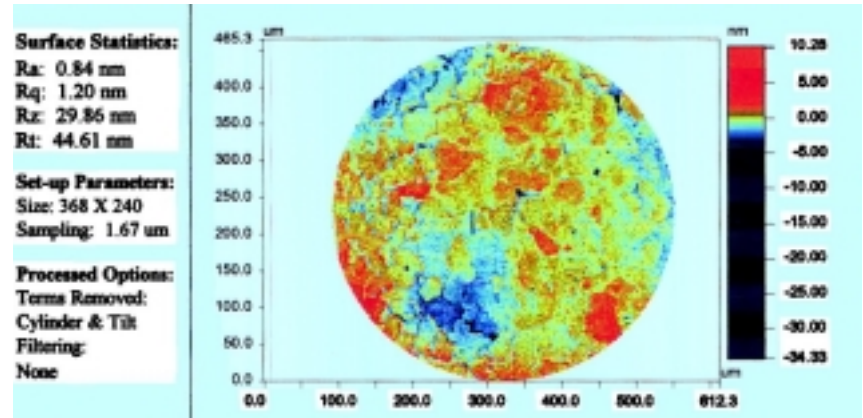


Silicon Carbide Optical Properties



•Spare ALI Primary Mirror Surface Figure

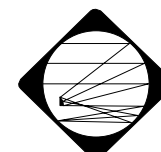
- Silicon coated SiC Asphere
- 0.035 λ RMS
- 0.294 λ Pk-valley



•Bare RB SiC Surface Finish

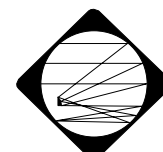
- Flat
- 12 Angstroms RMS

- Hot pressed and reaction bonded SiC materials demonstrated to provide excellent surface figures and surface finishes
 - Bare flats and spheres and silicon coated aspheres demonstrated on numerous programs
 - Surface finish achievable does depend the optical surface being polished
 - RB or HP SiC polishes to 10-15 Angstroms RMS routinely
 - Silicon coated SiC polishes to 20-30 Angstroms RMS routinely



Silicon Carbide Material Summary

- **SiC materials have been demonstrated to be suitable for LDCM and other future ALI-like missions**
 - Surface figure and image quality demonstrated with ALI flight system
 - Surface scatter demonstrated with spare ALI flight optic
- Combination of SiC and Invar materials used for ALI Optical Subsystem
 - Other alternatives can be used to better benefit from the excellent lightweighting capabilities possible with SiC materials
 - Hot pressed SiC optics and structure applied to MICAS DS-1 optical subsystem with good success
 - Reaction bonded SiC optics and structures allow a higher degree of lightweighting
 - ALI optical design can be implemented with more traditional optical materials
 - SSGPO has extensive experience in producing off-axis aspheric optics in aluminum, beryllium and low-expansion glasses



Optical Subsystem Technology Summary

- **ALI optical design well suited to address the unique demands associated with multi-spectral/hyper-spectral optical systems**
 - Excellent image quality and MTF
 - Low distortion
 - Near telecentric
 - Wide field of view
- **SiC materials demonstrated to meet all ALI optical requirements**
 - Surface figure and image quality demonstrated with ALI flight system
 - Surface scatter demonstrated with spare ALI flight optic
- **RB SiC materials can be applied to provide additional program benefits**
 - Significant cost savings
 - Significant weight savings

